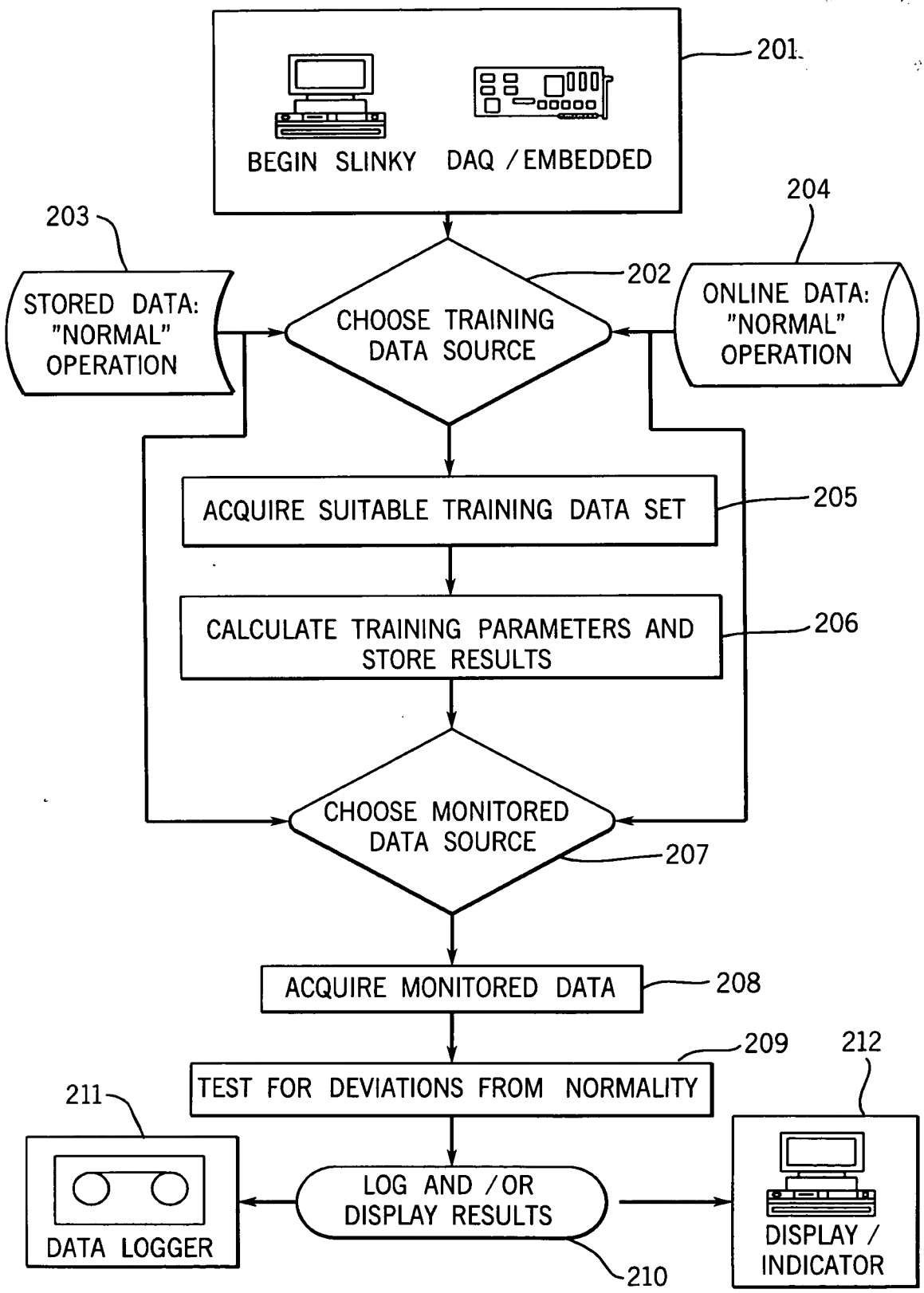

201
BEGIN SLINKY
DAQ / EMBEDDED
203
STORED DATA: "NORMAL" OPERATION
202
CHOOSE TRAINING DATA SOURCE
204
ONLINE DATA: "NORMAL" OPERATION
ACQUIRE SUITABLE TRAINING DATA SET
205
CALCULATE TRAINING PARAMETERS AND STORE RESULTS
206
CHOOSE MONITORED DATA SOURCE
207
ACQUIRE MONITORED DATA
208
TEST FOR DEVIATIONS FROM NORMALITY
209
212
211
DATA LOGGER
LOG AND / OR DISPLAY RESULTS
210
DISPLAY / INDICATOR

FIG. 1

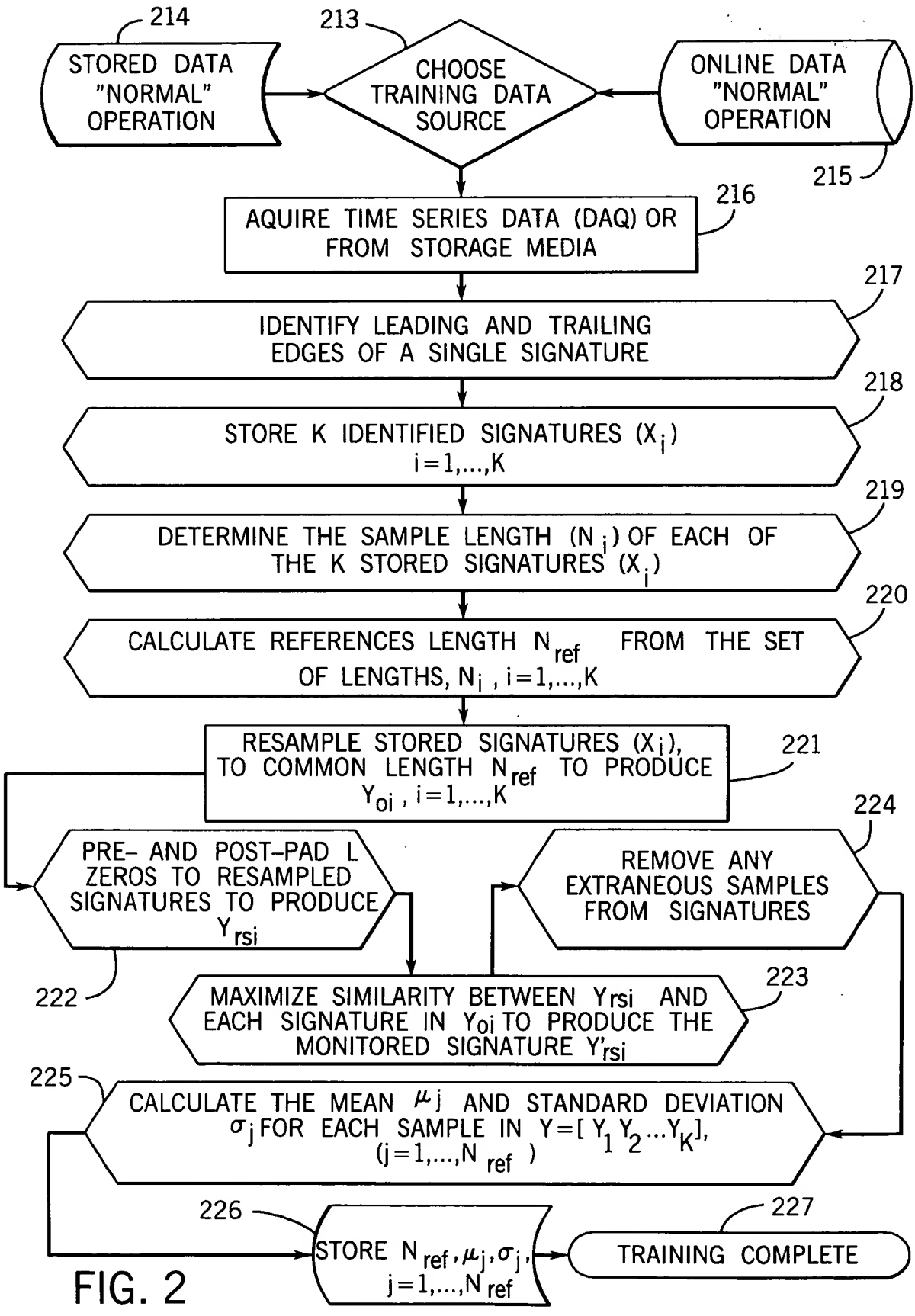

214
STORED DATA "NORMAL" OPERATION
213
CHOOSE TRAINING DATA SOURCE
ONLINE DATA "NORMAL" OPERATION
215
AQUIRE TIME SERIES DATA (DAQ) OR FROM STORAGE MEDIA
216
IDENTIFY LEADING AND TRAILING EDGES OF A SINGLE SIGNATURE
217
STORE K IDENTIFIED SIGNATURES (X_i) i=1,...,K
218
DETERMINE THE SAMPLE LENGTH (N_i) OF EACH OF THE K STORED SIGNATURES (X_i)
219
CALCULATE REFERENCES LENGTH N_{ref} FROM THE SET OF LENGTHS, N_i, i=1,...,K
220
RESAMPLE STORED SIGNATURES (X_i), TO COMMON LENGTH N_{ref} TO PRODUCE Y_{oi}, i=1,...,K
221
PRE- AND POST-PAD L ZEROS TO RESAMPLED SIGNATURES TO PRODUCE Y_{rsi}
222
REMOVE ANY EXTRANEOUS SAMPLES FROM SIGNATURES
224
MAXIMIZE SIMILARITY BETWEEN Y_{rsi} AND EACH SIGNATURE IN Y_{oi} TO PRODUCE THE MONITORED SIGNATURE Y'_{rsi}
223
CALCULATE THE MEAN μ_j AND STANDARD DEVIATION σ_j FOR EACH SAMPLE IN $Y=[Y_1 Y_2 ... Y_K]$, $(j=1,...,N_{ref})$
225
STORE N_{ref}, μ_j, σ_j, j=1,...,N_{ref}
226
TRAINING COMPLETE
227

FIG. 2

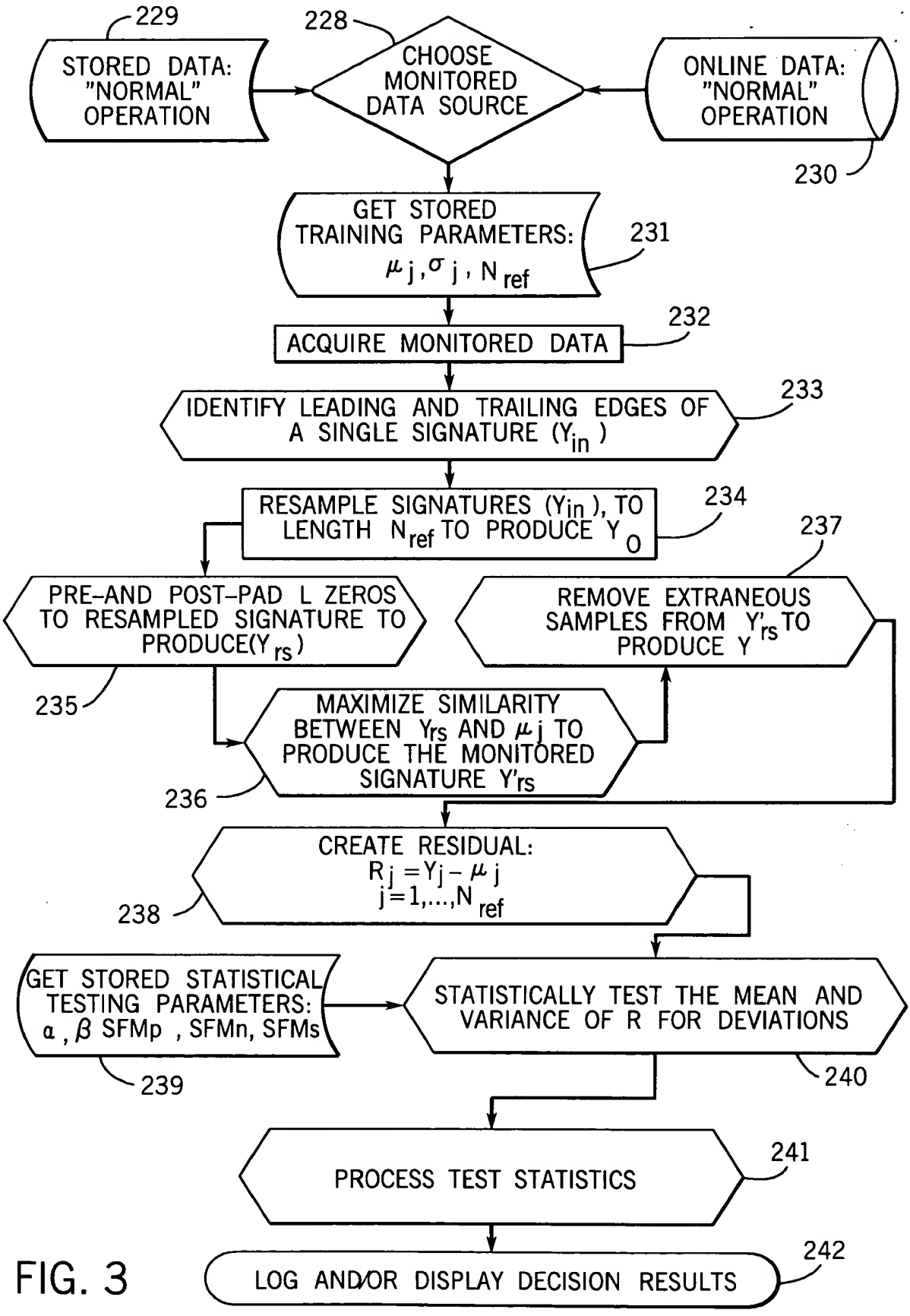

229
STORED DATA: "NORMAL" OPERATION
228
CHOOSE MONITORED DATA SOURCE
ONLINE DATA: "NORMAL" OPERATION
230
GET STORED TRAINING PARAMETERS: μ_j, σ_j, N_{ref}
231
ACQUIRE MONITORED DATA
232
IDENTIFY LEADING AND TRAILING EDGES OF A SINGLE SIGNATURE (Y_{in})
233
RESAMPLE SIGNATURES (Y_{in}), TO LENGTH N_{ref} TO PRODUCE Y_0
234
PRE-AND POST-PAD L ZEROS TO RESAMPLED SIGNATURE TO PRODUCE(Y_{rs})
235
REMOVE EXTRANEOUS SAMPLES FROM Y'_{rs} TO PRODUCE Y
237
MAXIMIZE SIMILARITY BETWEEN Y_{rs} AND μ_j TO PRODUCE THE MONITORED SIGNATURE Y'_{rs}
236
CREATE RESIDUAL: $R_j = Y_j - \mu_j$ $j=1,\ldots,N_{ref}$
238
GET STORED STATISTICAL TESTING PARAMETERS: α, β SFMp, SFMn, SFMs
239
STATISTICALLY TEST THE MEAN AND VARIANCE OF R FOR DEVIATIONS
240
PROCESS TEST STATISTICS
241
LOG AND/OR DISPLAY DECISION RESULTS
242

FIG. 3

FIG. 4A

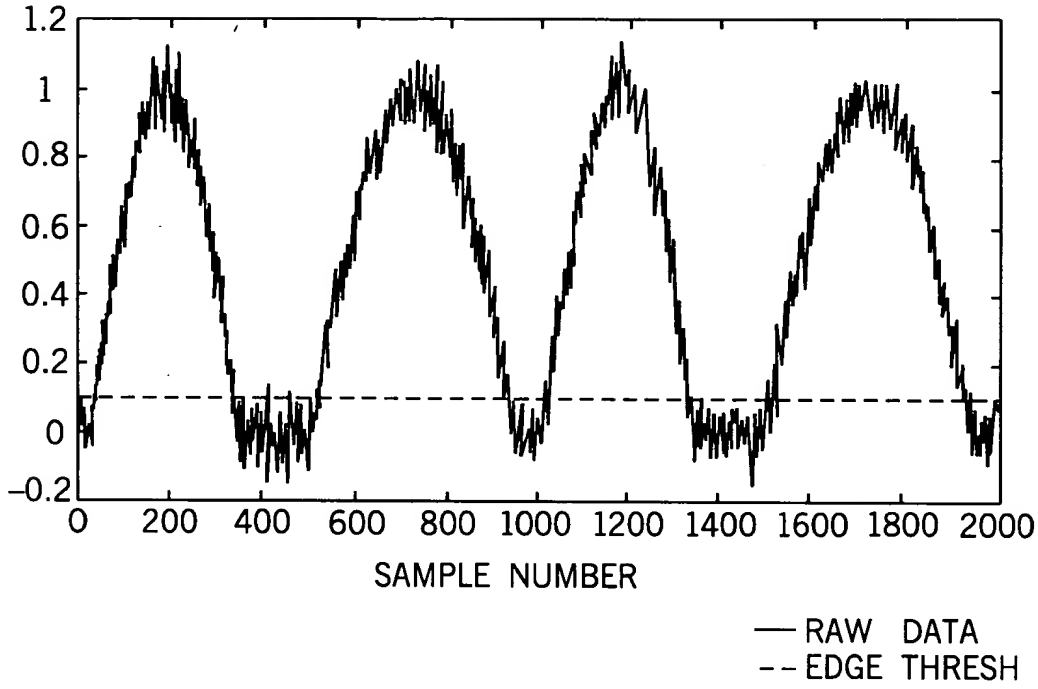
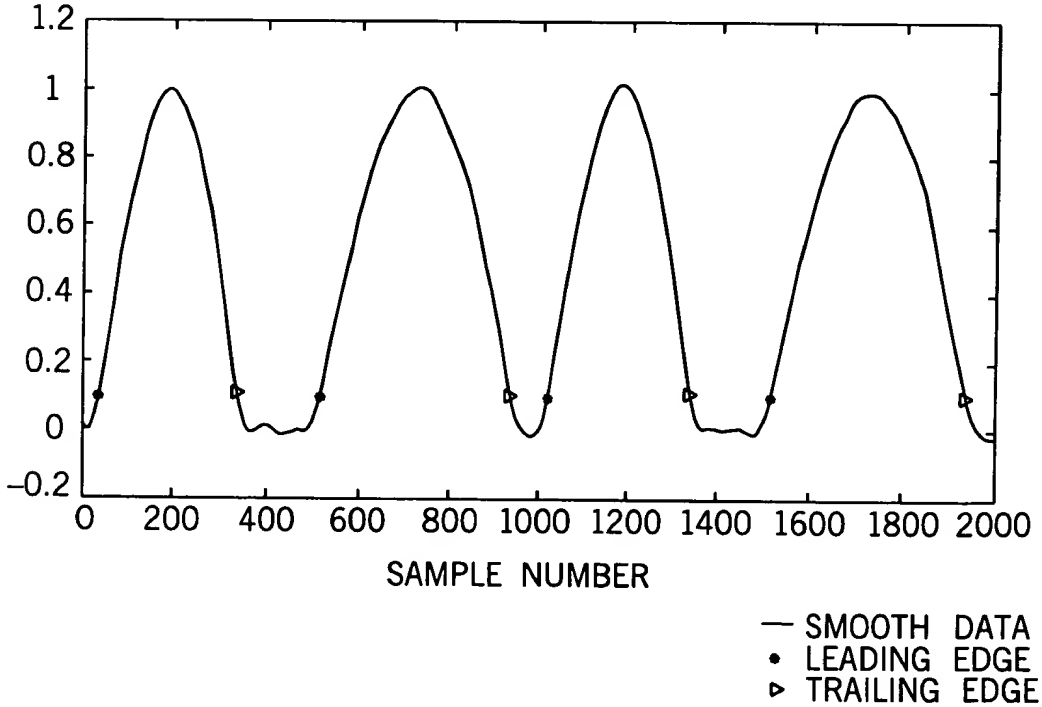

1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0 200 400 600 800 1000 1200 1400 1600 1800 2000
SAMPLE NUMBER
RAW DATA
EDGE THRESH

FIG. 4B


1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0 200 400 600 800 1000 1200 1400 1600 1800 2000
SAMPLE NUMBER
SMOOTH DATA
LEADING EDGE
TRAILING EDGE

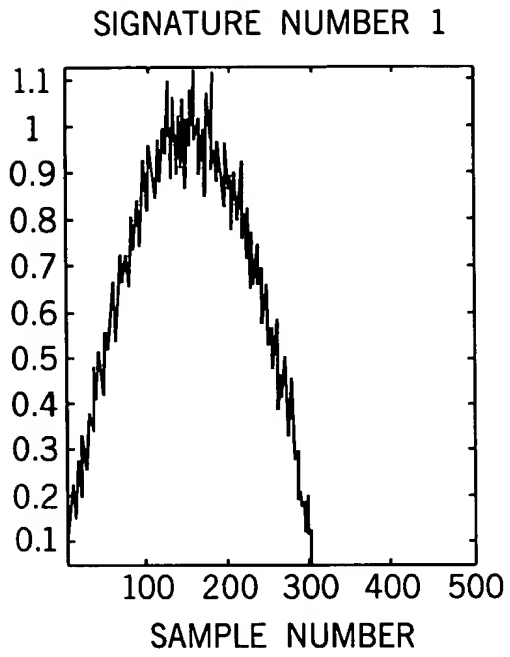


FIG.5A

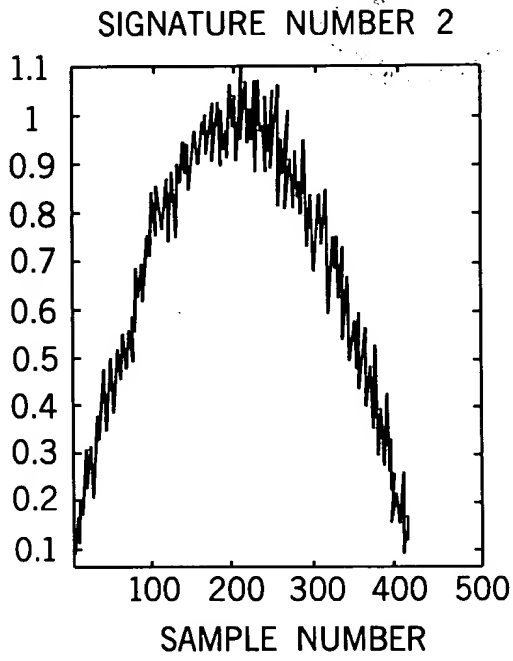


FIG.5B

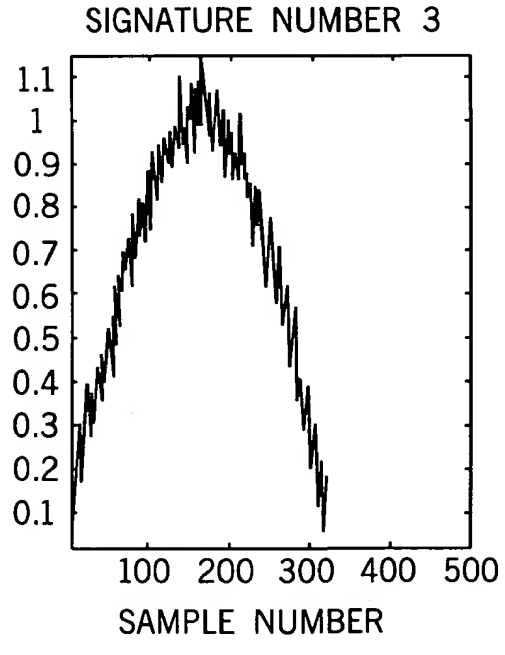


FIG.5C

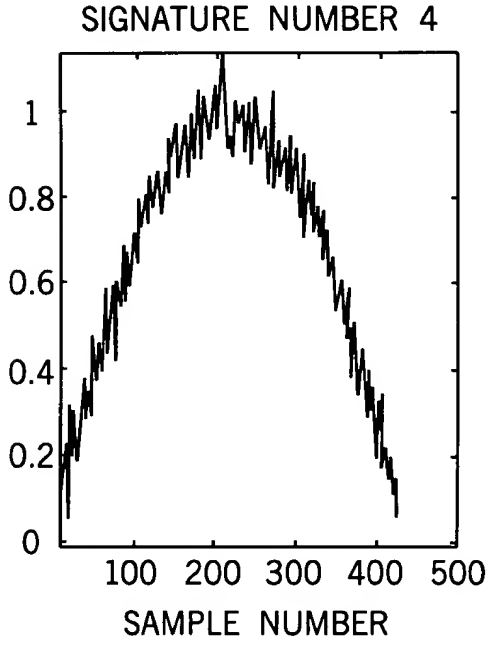


FIG. 5D

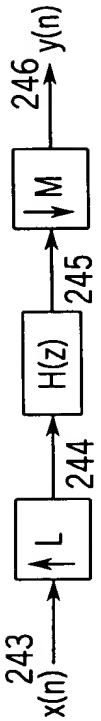
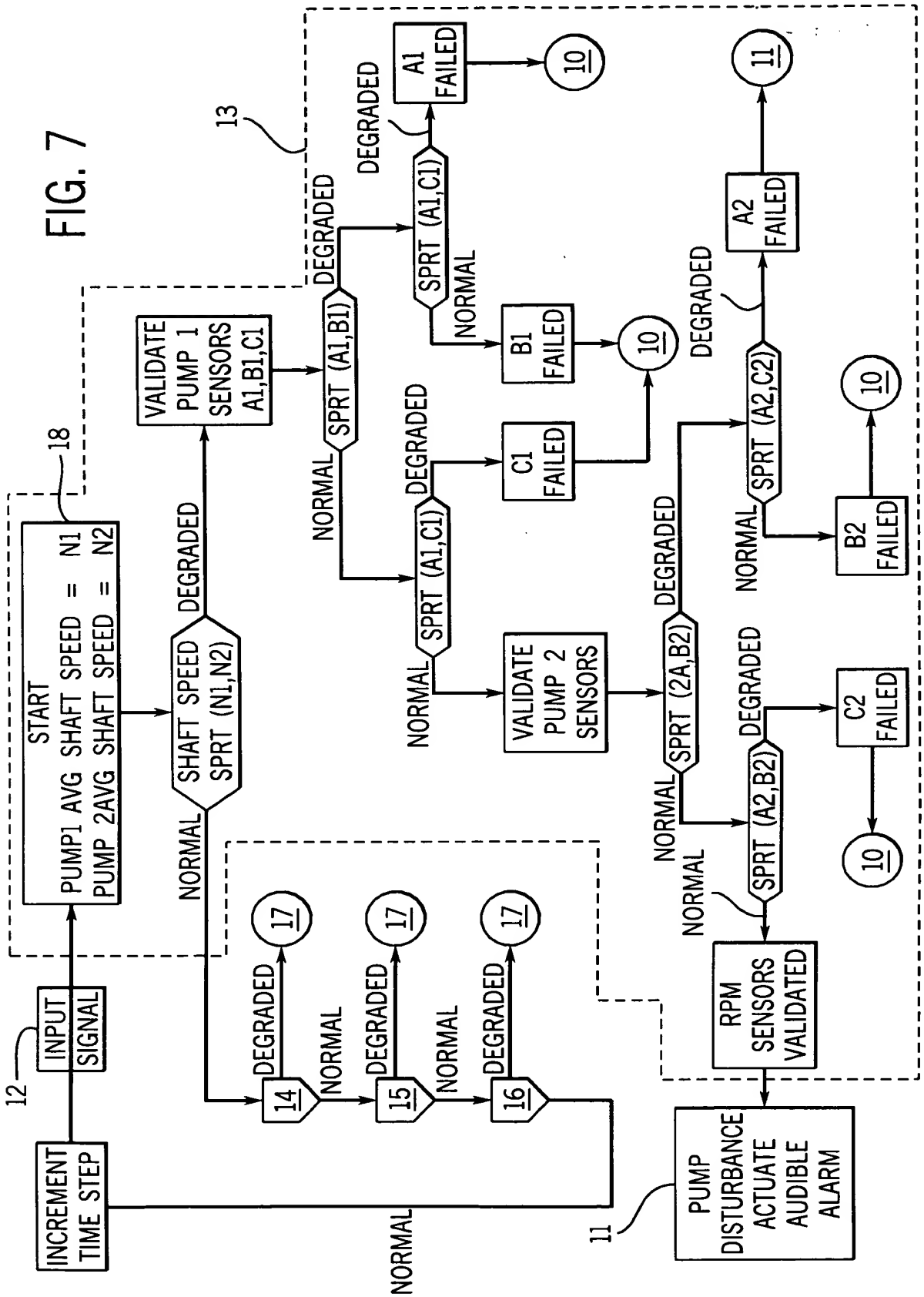


FIG. 6

FIG. 7


INCREMENT TIME STEP
INPUT SIGNAL
12
START
PUMP1 AVG SHAFT SPEED = N1
PUMP 2AVG SHAFT SPEED = N2
18
SHAFT SPEED SPRT (N1,N2)
NORMAL
DEGRADED
VALIDATE PUMP 1 SENSORS A1,B1,C1
13
SPRT (A1,B1)
NORMAL
DEGRADED
SPRT (A1,C1)
NORMAL
DEGRADED
A1 FAILED
10
B1 FAILED
10
C1 FAILED
10
VALIDATE PUMP 2 SENSORS
SPRT (2A,B2)
NORMAL
DEGRADED
SPRT (A2,C2)
NORMAL
DEGRADED
A2 FAILED
11
B2 FAILED
10
SPRT (A2,B2)
NORMAL
DEGRADED
C2 FAILED
10
RPM SENSORS VALIDATED
14
NORMAL
DEGRADED
17
15
NORMAL
DEGRADED
17
16
NORMAL
DEGRADED
17
NORMAL
11
PUMP DISTURBANCE ACTUATE AUDIBLE ALARM

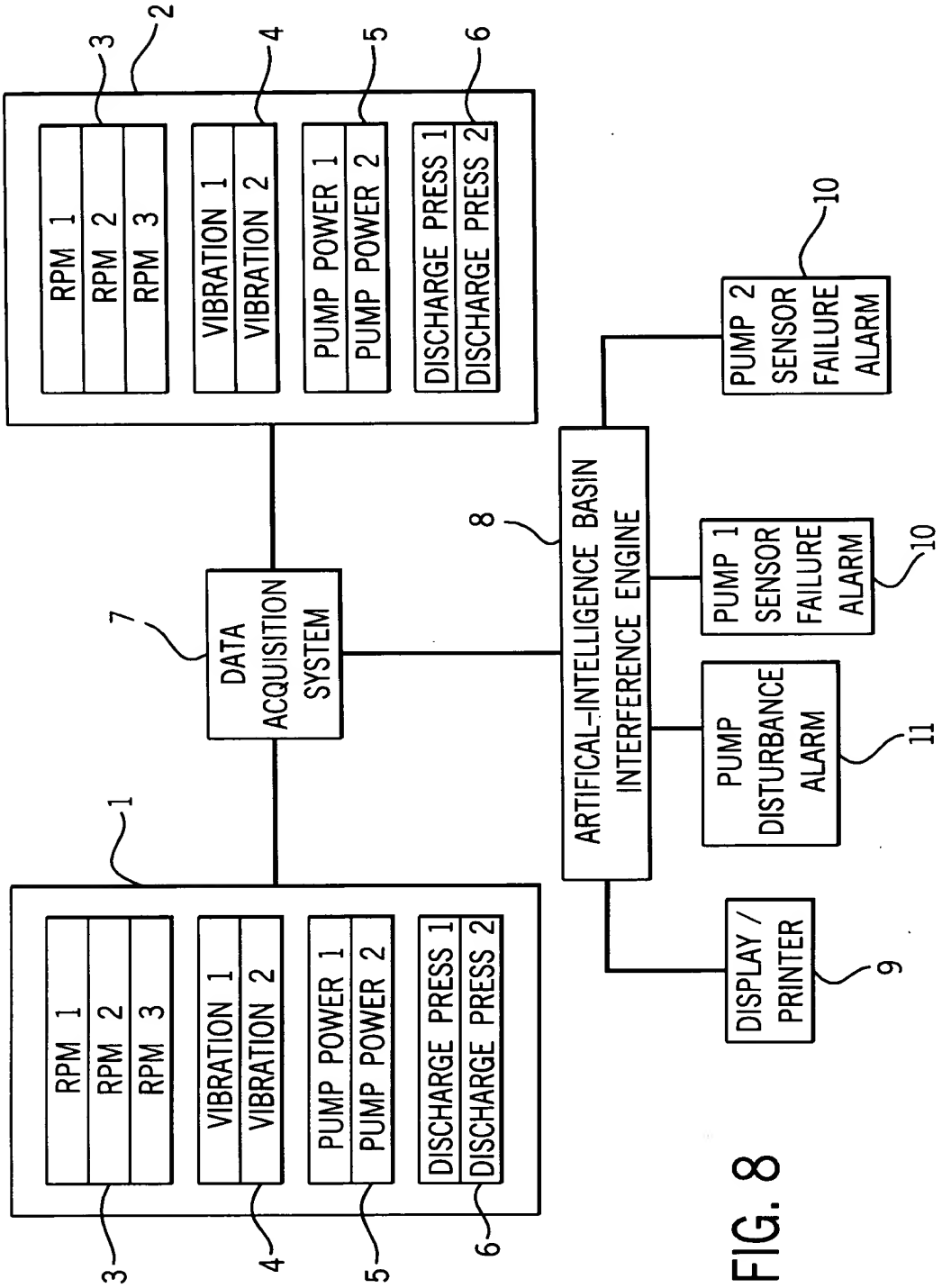

RPM 1
RPM 2
RPM 3
VIBRATION 1
VIBRATION 2
PUMP POWER 1
PUMP POWER 2
DISCHARGE PRESS 1
DISCHARGE PRESS 2
DATA ACQUISITION SYSTEM
ARTIFICAL-INTELLIGENCE BASIN INTERFERENCE ENGINE
PUMP 2 SENSOR FAILURE ALARM
PUMP 1 SENSOR FAILURE ALARM
PUMP DISTURBANCE ALARM
DISPLAY / PRINTER
1
2
3
4
5
6
7
8
9
10
11

FIG. 8

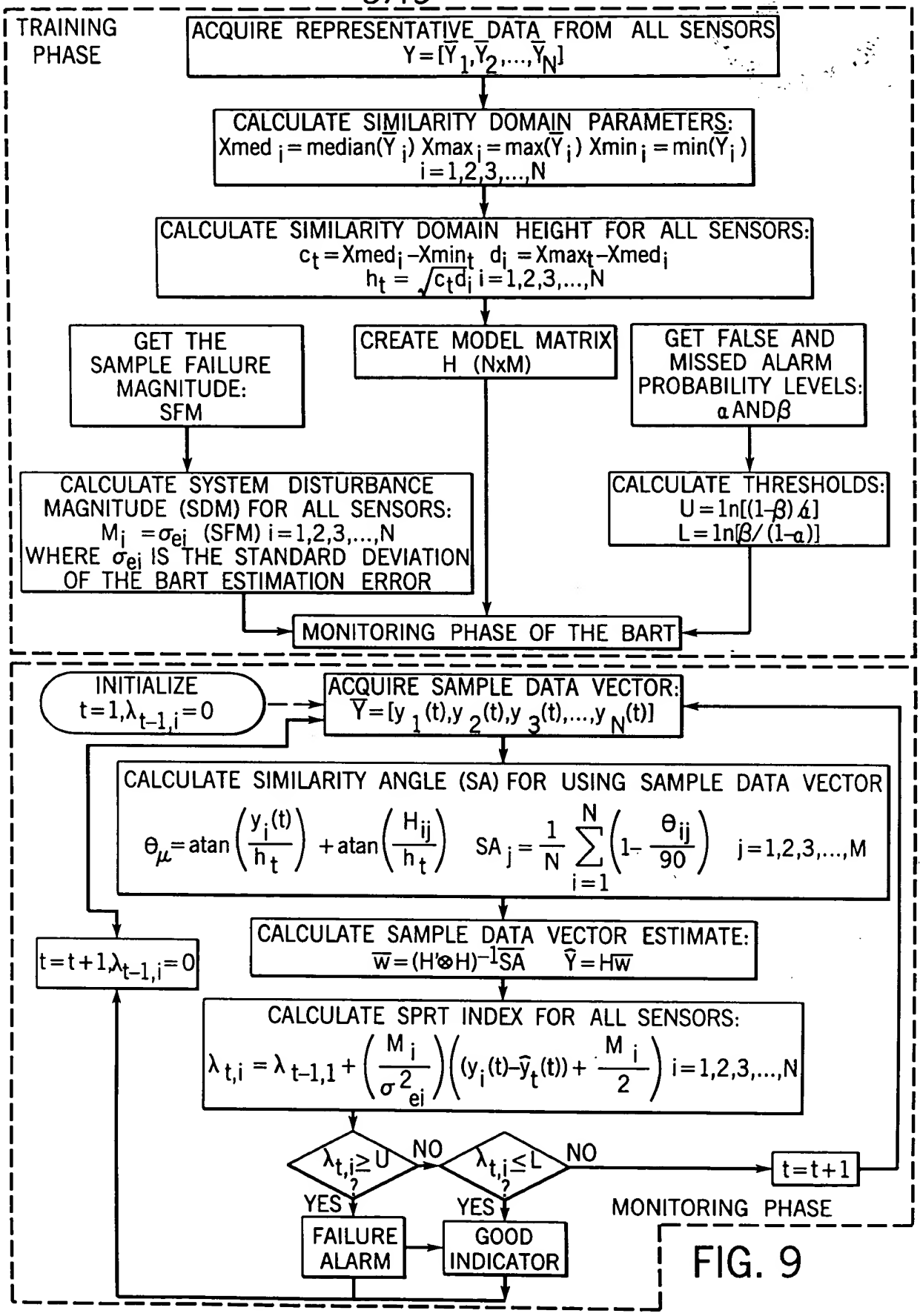

TRAINING PHASE
ACQUIRE REPRESENTATIVE DATA FROM ALL SENSORS
$Y=[\bar{Y}_1,\bar{Y}_2,\ldots,\bar{Y}_N]$
CALCULATE SIMILARITY DOMAIN PARAMETERS:
$Xmed_i = median(\bar{Y}_i)$ $Xmax_i = max(\bar{Y}_i)$ $Xmin_i = min(\bar{Y}_i)$
$i=1,2,3,\ldots,N$
CALCULATE SIMILARITY DOMAIN HEIGHT FOR ALL SENSORS:
$c_t = Xmed_i - Xmin_t$ $d_i = Xmax_t - Xmed_i$
$h_t = \sqrt{c_t d_i}$ $i=1,2,3,\ldots,N$
GET THE SAMPLE FAILURE MAGNITUDE: SFM
CREATE MODEL MATRIX H (NxM)
GET FALSE AND MISSED ALARM PROBABILITY LEVELS: α AND β
CALCULATE SYSTEM DISTURBANCE MAGNITUDE (SDM) FOR ALL SENSORS:
$M_i = \sigma_{ei}$ (SFM) $i=1,2,3,\ldots,N$
WHERE σ_{ei} IS THE STANDARD DEVIATION OF THE BART ESTIMATION ERROR
CALCULATE THRESHOLDS:
$U=\ln[(1-\beta)/\alpha]$
$L=\ln[\beta/(1-\alpha)]$
MONITORING PHASE OF THE BART
INITIALIZE
$t=1, \lambda_{t-1,i}=0$
ACQUIRE SAMPLE DATA VECTOR:
$\bar{Y}=[y_1(t),y_2(t),y_3(t),\ldots,y_N(t)]$
CALCULATE SIMILARITY ANGLE (SA) FOR USING SAMPLE DATA VECTOR
$\theta_\mu = \text{atan}\left(\frac{y_i(t)}{h_t}\right) + \text{atan}\left(\frac{H_{ij}}{h_t}\right)$ $SA_j = \frac{1}{N}\sum_{i=1}^{N}\left(1-\frac{\theta_{ij}}{90}\right)$ $j=1,2,3,\ldots,M$
CALCULATE SAMPLE DATA VECTOR ESTIMATE:
$\bar{w}=(H'\otimes H)^{-1}\bar{SA}$ $\hat{Y}=H\bar{w}$
$t=t+1, \lambda_{t-1,i}=0$
CALCULATE SPRT INDEX FOR ALL SENSORS:
$\lambda_{t,i} = \lambda_{t-1,1} + \left(\frac{M_i}{\sigma^2_{ei}}\right)\left((y_i(t)-\hat{y}_t(t)) + \frac{M_i}{2}\right)$ $i=1,2,3,\ldots,N$
$\lambda_{t,i} \geq U$?
NO
$\lambda_{t,i} \leq L$?
NO
$t=t+1$
YES
YES
FAILURE ALARM
GOOD INDICATOR
MONITORING PHASE

FIG. 9

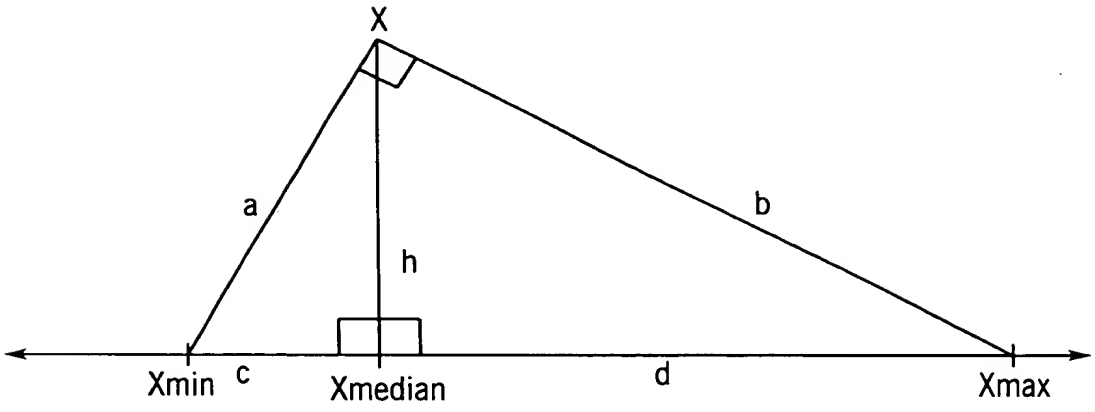

X
a
b
h
Xmin
c
Xmedian
d
Xmax

FIG. 10

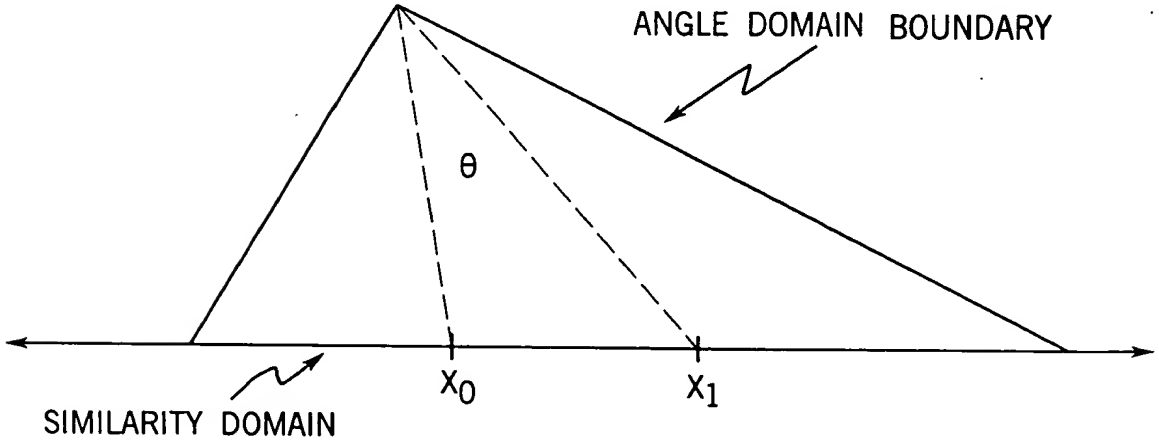

ANGLE DOMAIN BOUNDARY
θ
X0
X1
SIMILARITY DOMAIN

FIG. 11

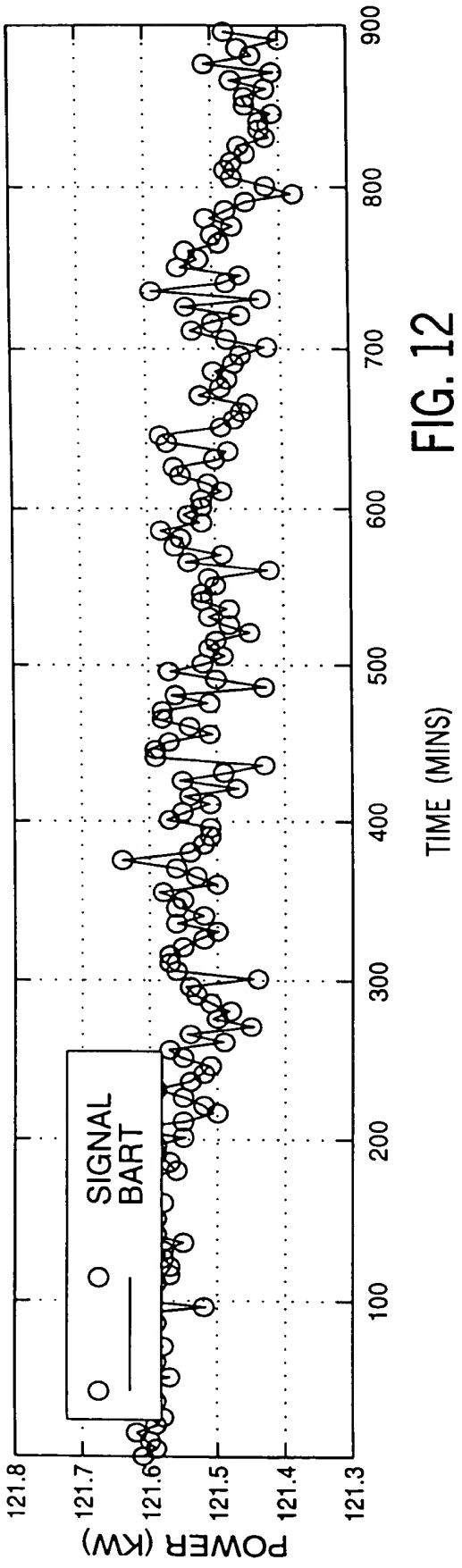

POWER (KW)
121.8
121.7
121.6
121.5
121.4
121.3
100
200
300
400
500
600
700
800
900
TIME (MINS)
SIGNAL
BART

FIG. 12

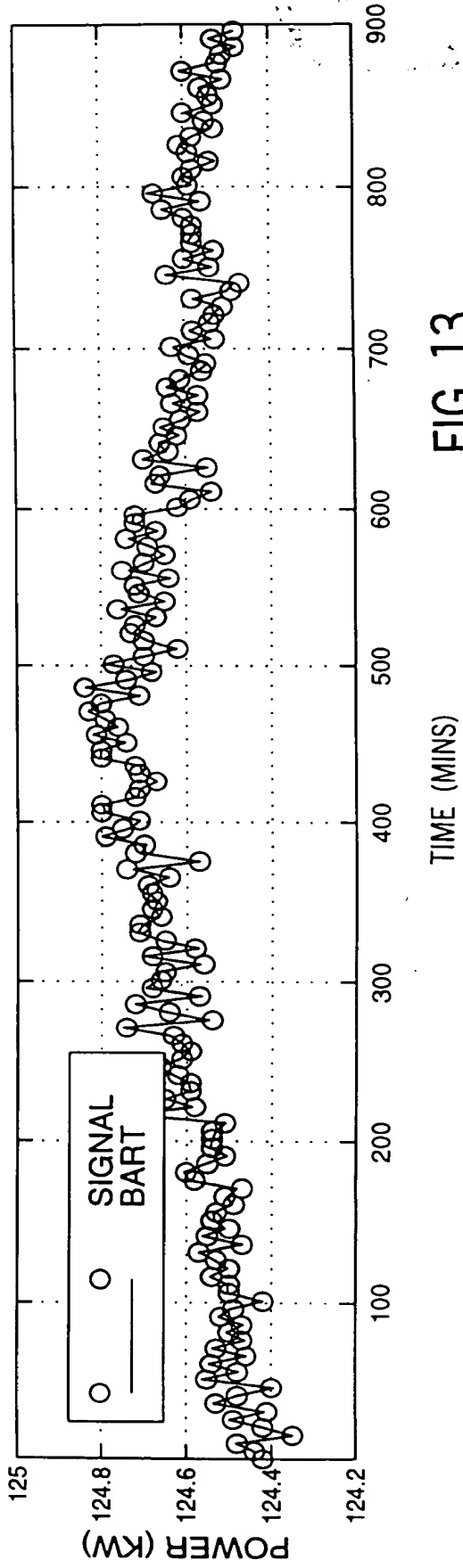

POWER (KW)
125
124.8
124.6
124.4
124.2
100
200
300
400
500
600
700
800
900
TIME (MINS)
SIGNAL
BART

FIG. 13

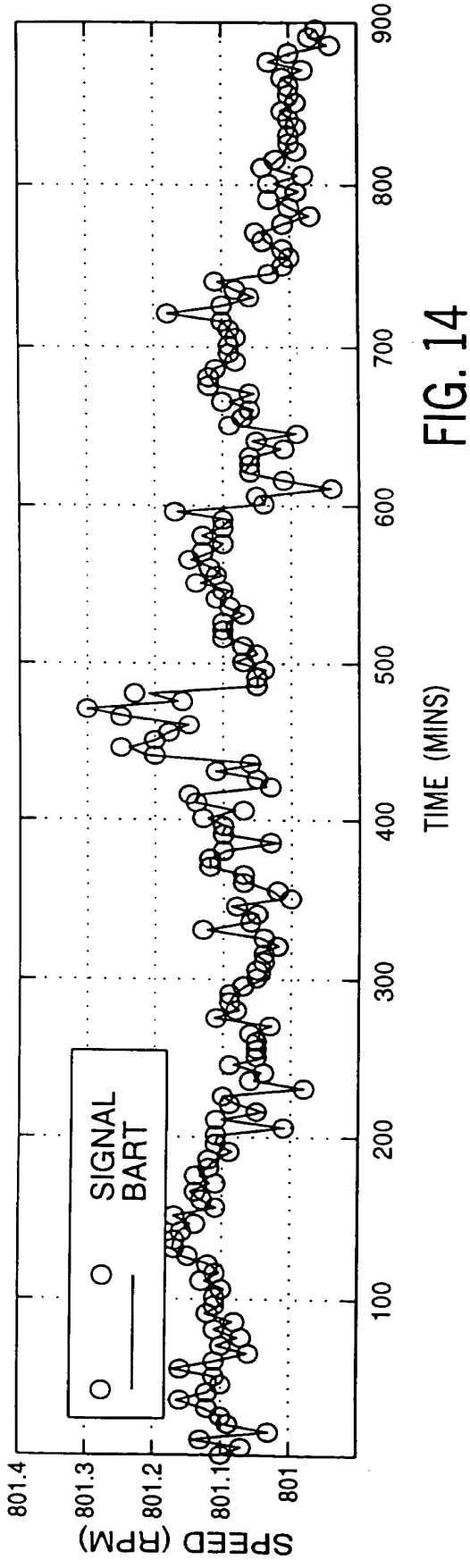

SIGNAL
BART
SPEED (RPM)
801.4
801.3
801.2
801.1
801
TIME (MINS)
100
200
300
400
500
600
700
800
900

FIG. 14

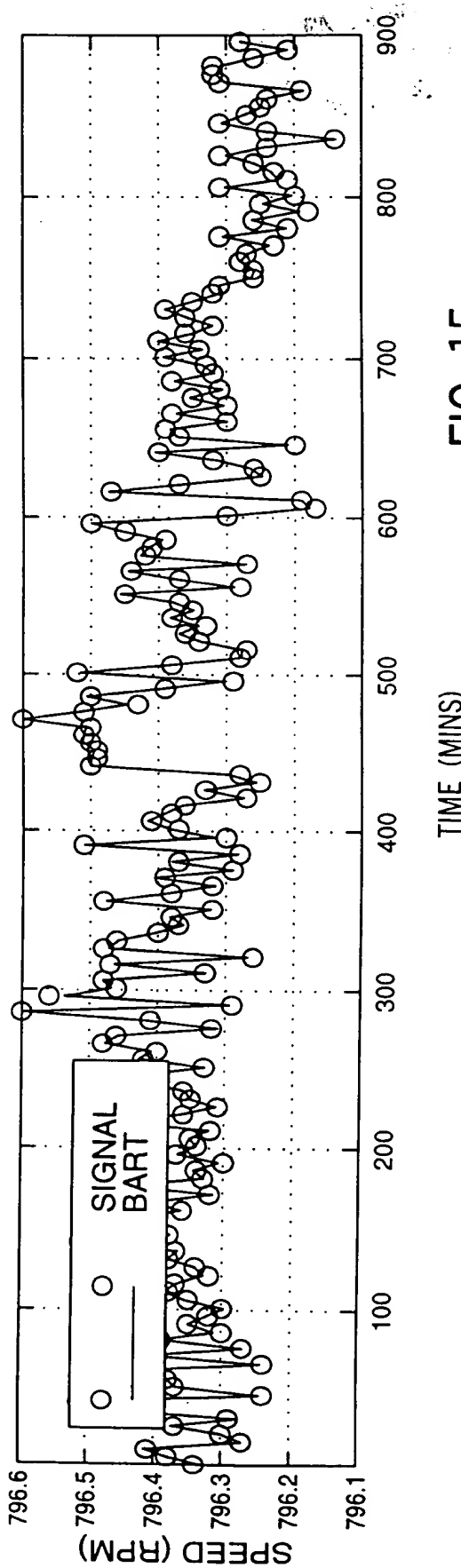

SIGNAL
BART
SPEED (RPM)
796.6
796.5
796.4
796.3
796.2
796.1
TIME (MINS)
100
200
300
400
500
600
700
800
900

FIG. 15

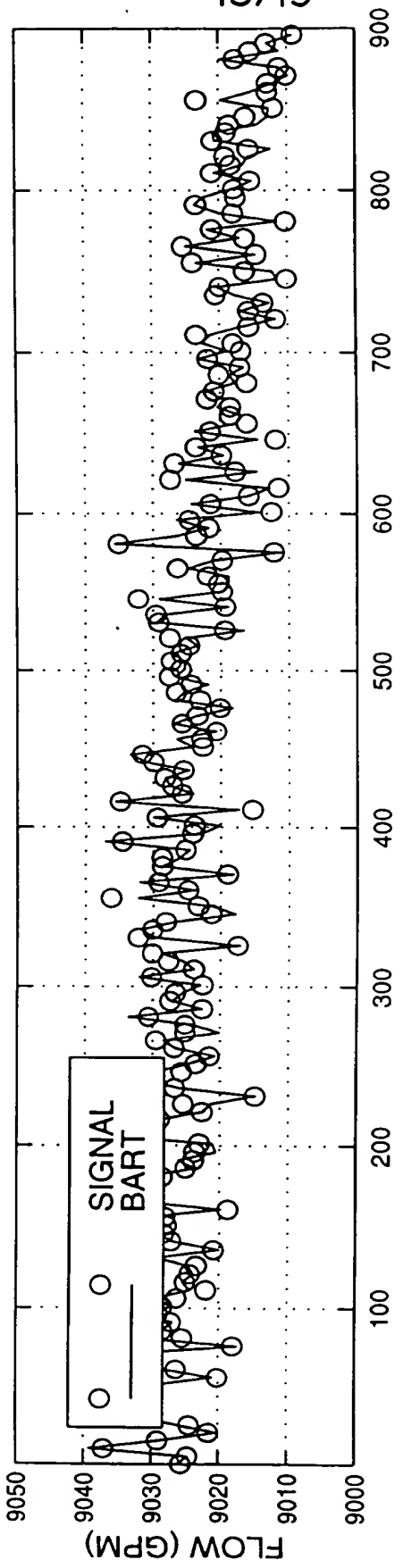

SIGNAL
BART
FLOW (GPM)
9050
9040
9030
9020
9010
9000
100
200
300
400
500
600
700
800
900
TIME (MINS)

FIG. 16

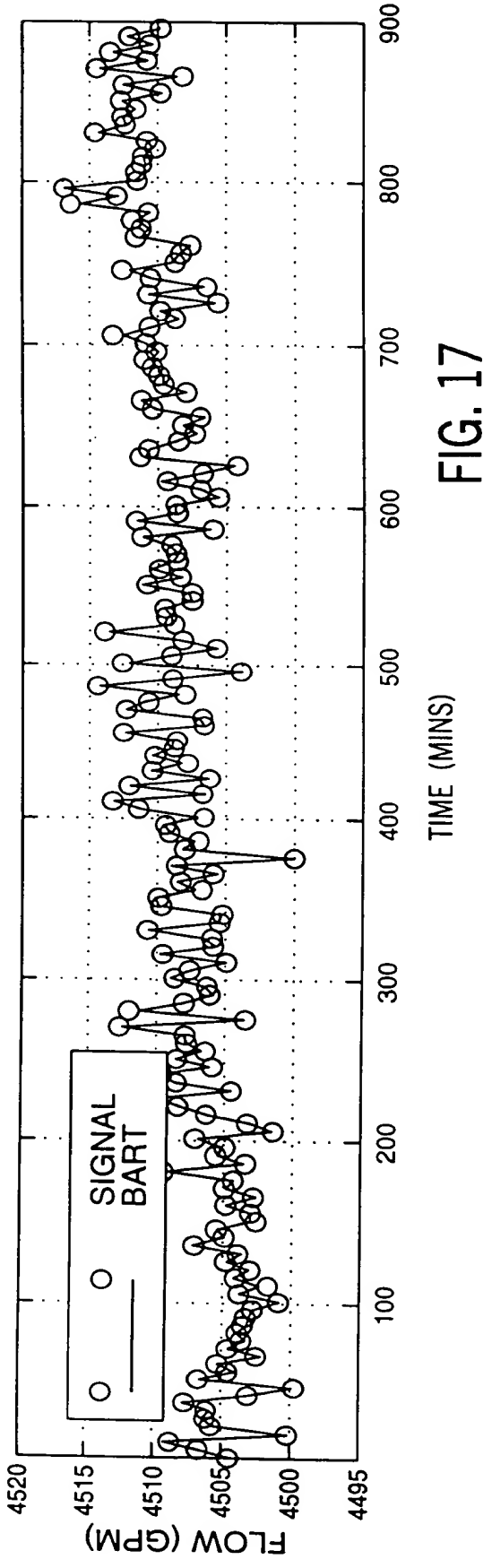

FLOW (GPM)
4520
4515
4510
4505
4500
4495
100
200
300
400
500
600
700
800
900
TIME (MINS)
SIGNAL
BART

FIG. 17

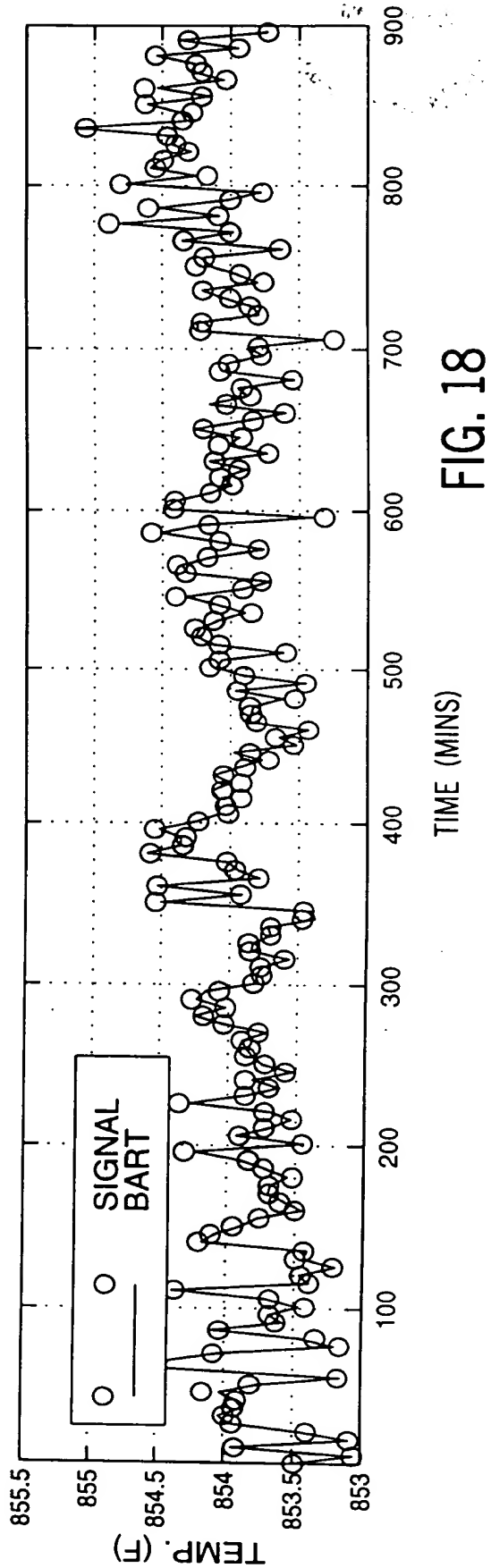

TEMP. (F)
855.5
855
854.5
854
853.5
853
100
200
300
400
500
600
700
800
900
TIME (MINS)
SIGNAL
BART

FIG. 18

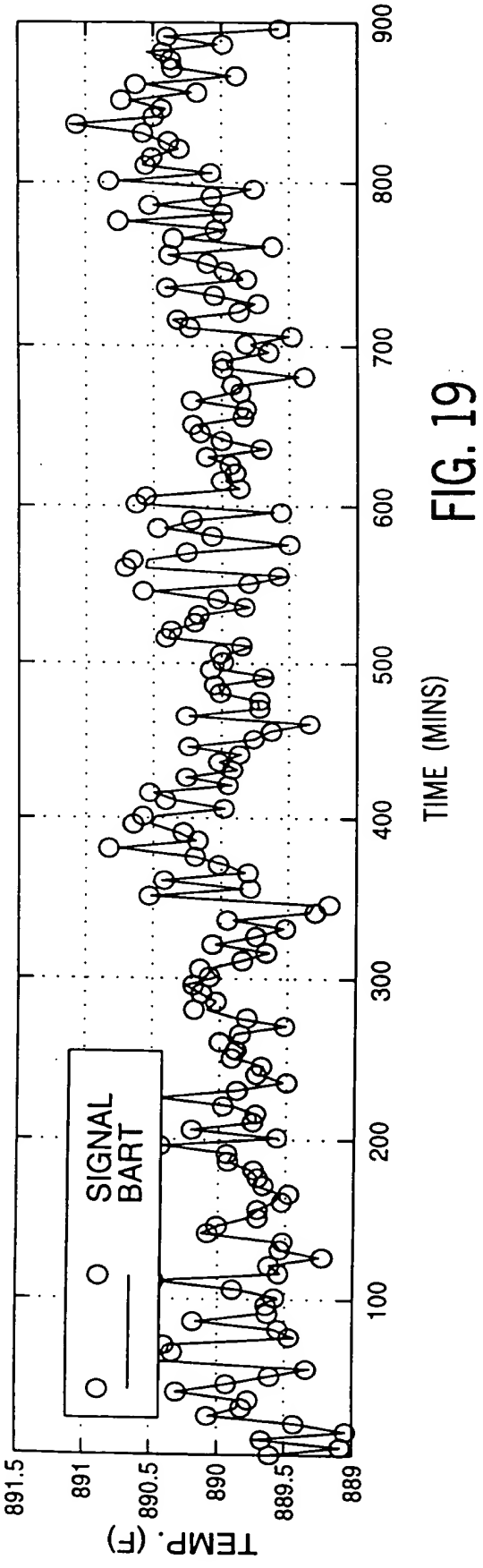

TEMP. (F)
891.5
891
890.5
890
889.5
889
100
200
300
400
500
600
700
800
900
TIME (MINS)
SIGNAL
BART

FIG. 19

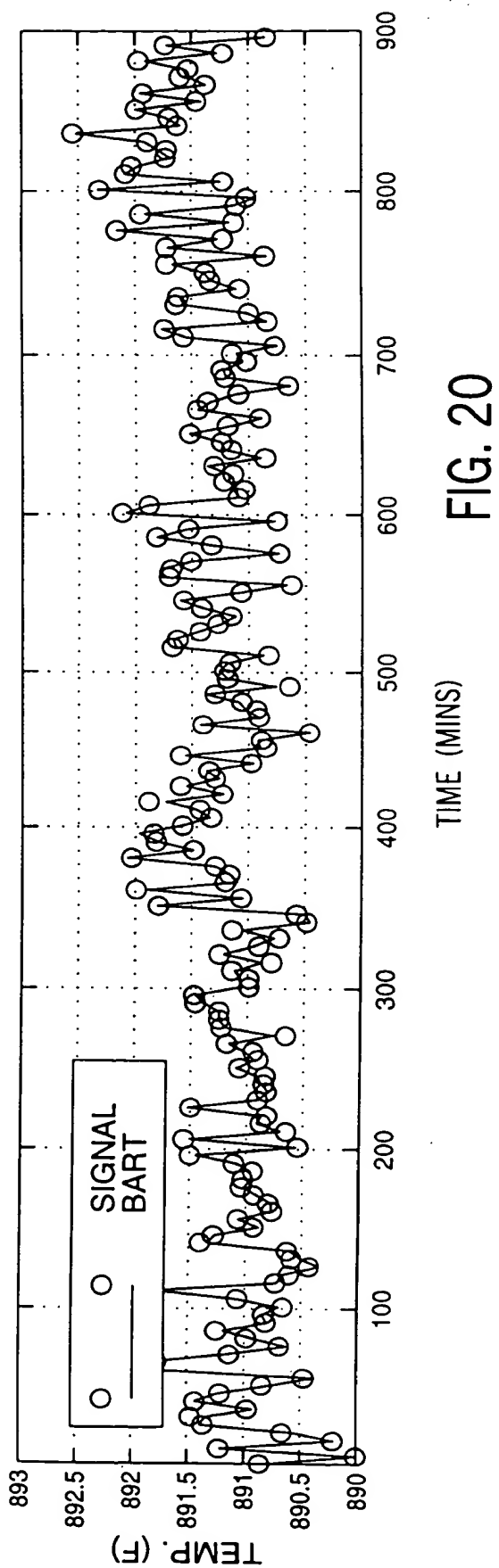

TEMP. (F)
893
892.5
892
891.5
891
890.5
890
100
200
300
400
500
600
700
800
900
TIME (MINS)
SIGNAL
BART

FIG. 20

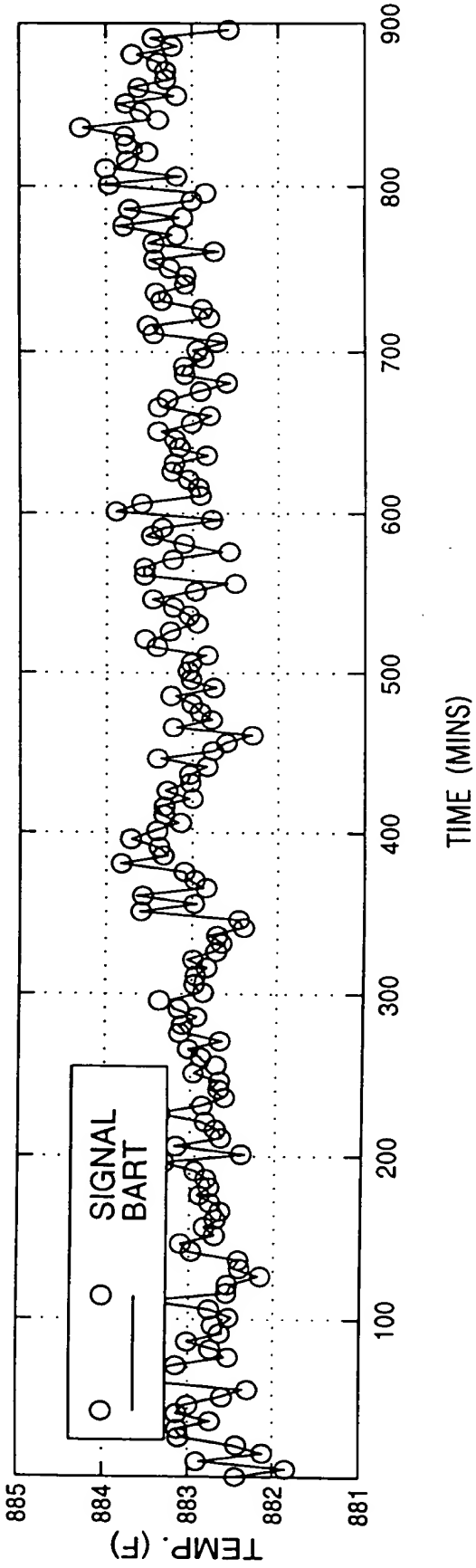

TEMP. (F)
885
884
883
882
881
100
200
300
400
500
600
700
800
900
TIME (MINS)
SIGNAL
BART

FIG. 21

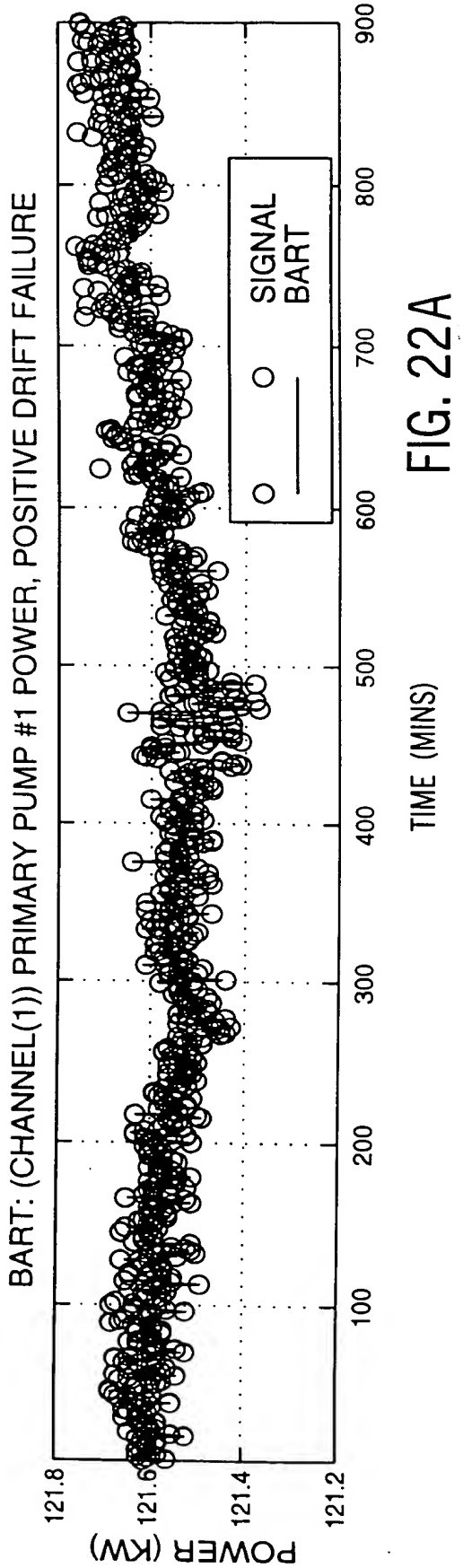


FIG. 22A

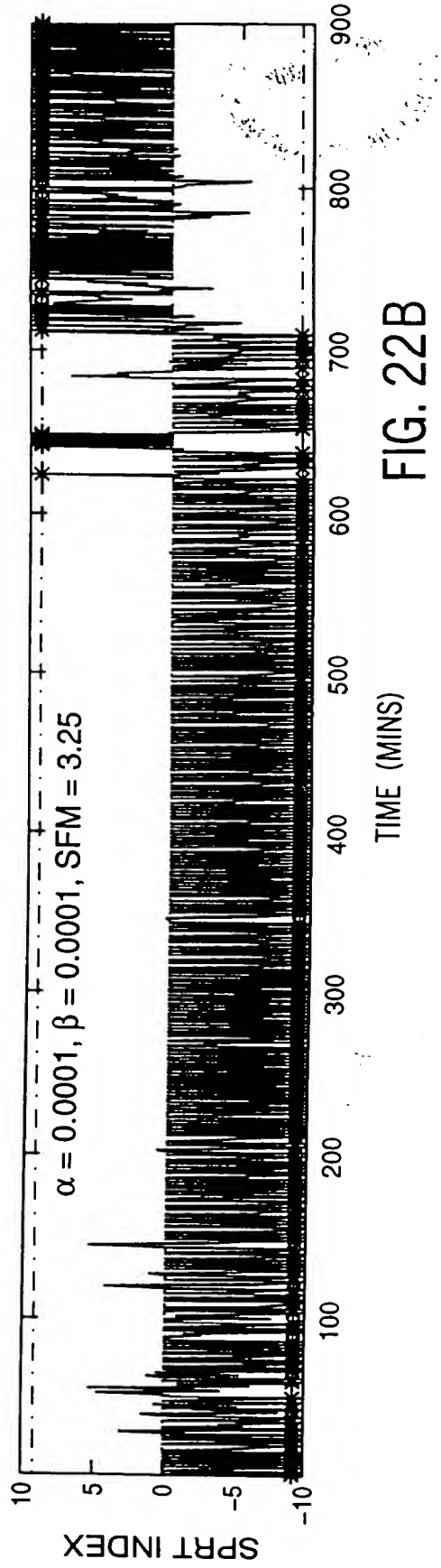


FIG. 22B

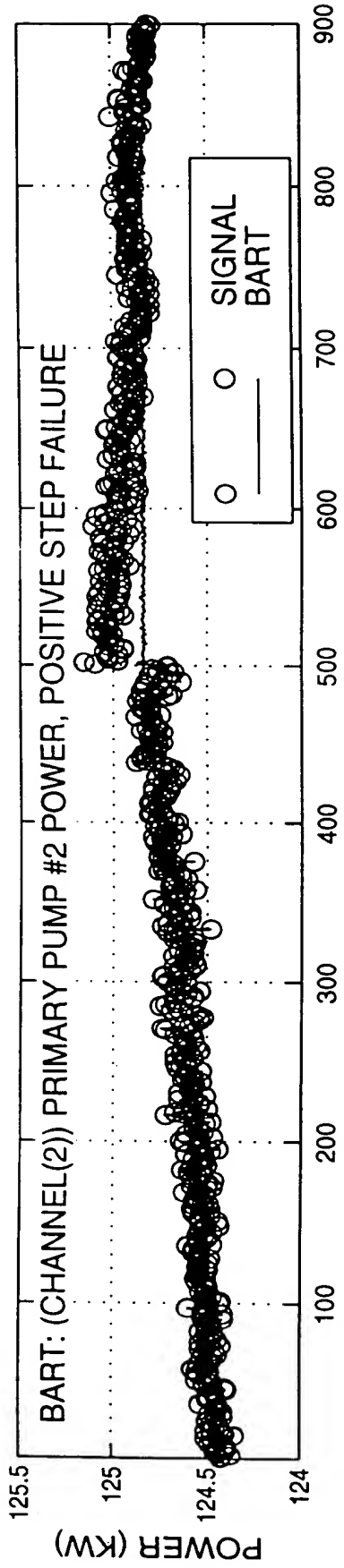


FIG. 22C

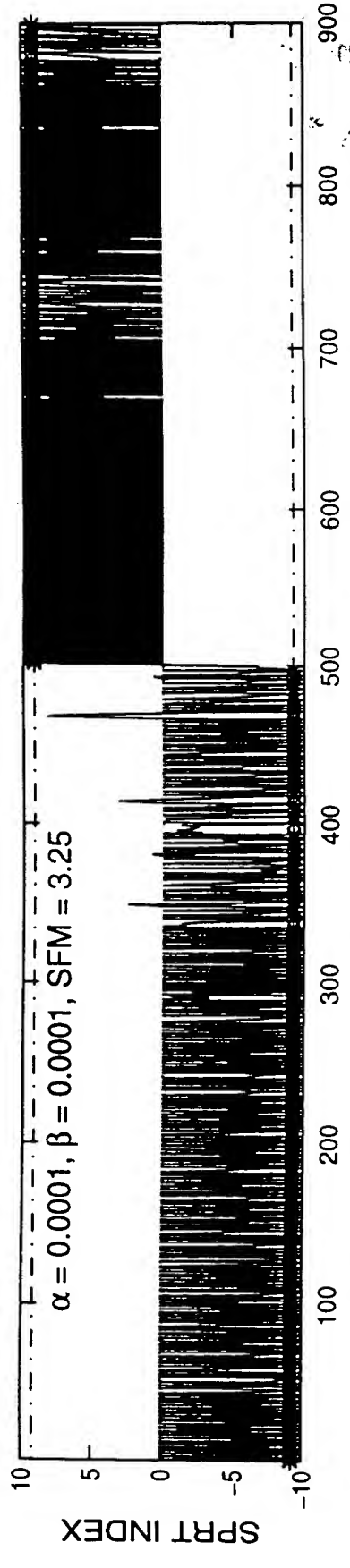


FIG. 22D

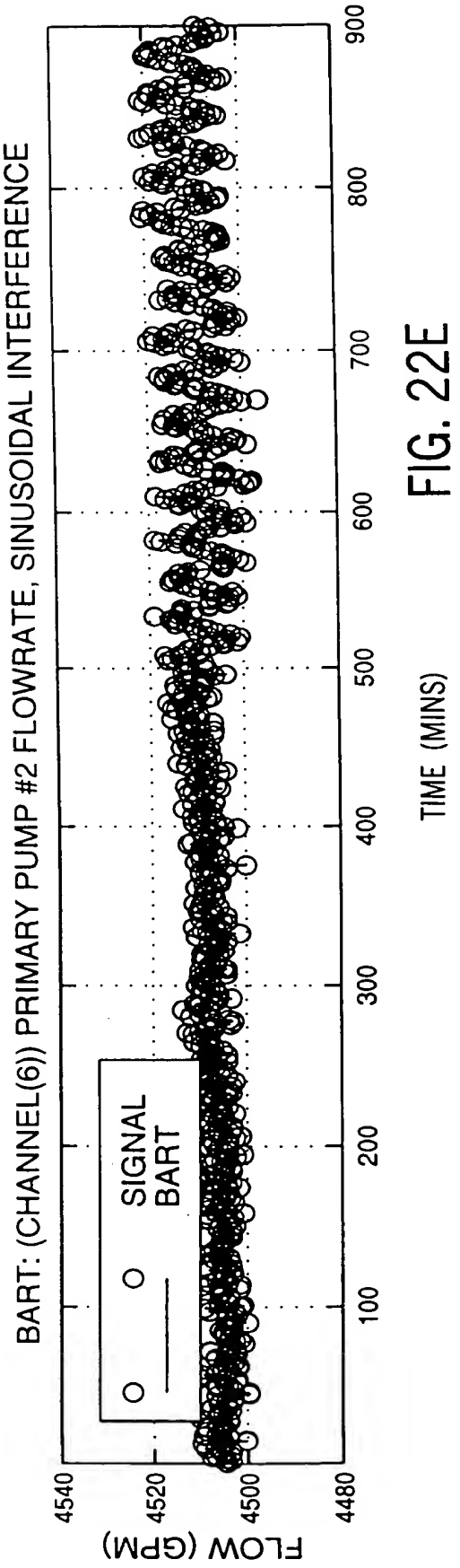


FIG. 22E

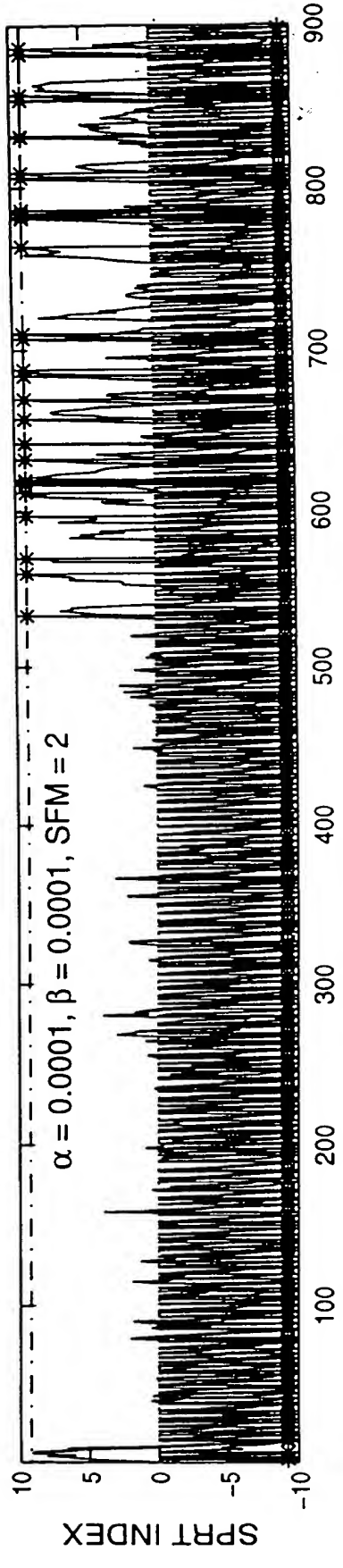


FIG. 22F